

CHAPTER 3

AIRCRAFT WEIGHT AND BALANCE

PURPOSE

The primary purpose of aircraft weight and balance control is safety. A secondary purpose is to achieve the utmost in efficiency during flight.

Improper loading reduces the efficiency of an aircraft from the standpoint of ceiling, maneuverability, rate of climb, speed, and fuel consumption. It can be the cause of failure to complete a flight, or even to start it. Possible loss of life and destruction of valuable equipment may result from overstressed structures or from a sudden shift in cargo and consequent change in flight characteristics.

The empty weight and the corresponding c.g. (center of gravity) of all civil aircraft must be determined at the time of certification. The manufacturer can weigh the aircraft, or he can compute the weight and balance report. A manufacturer is permitted to weigh one aircraft out of each 10 produced. The remaining nine aircraft are issued a computed weight and balance report based on the averaged figures of aircraft that are actually weighed. The condition of the aircraft at the time of determining empty weight must be one that is well defined and can be easily repeated.

NEED FOR REWEIGHING

Aircraft have a tendency to gain weight because of the accumulation of dirt, greases, etc., in areas not readily accessible for washing and cleaning. The weight gained in any given period of time will depend on the function of the aircraft, its hours in flight, atmospheric conditions, and the type landing field from which it is operating. For this reason, periodic aircraft weighings are desirable and, in the case of air carrier and air taxi aircraft, are required by Federal Aviation Regulations.

Privately owned and operated aircraft are not required by regulation to be weighed periodically. They are usually weighed when originally certificated, or after making major alterations that can affect the weight and balance. Even though the

aircraft need not be weighed, it must be loaded so that the maximum weight and c.g. limits are not exceeded during operation.

Airline aircraft (scheduled and nonscheduled) carrying passengers or cargo are subject to certain rules that require owners to show that the aircraft is properly loaded and will not exceed the authorized weight and balance limitations during operation.

THEORY OF WEIGHT AND BALANCE

The theory of weight and balance is extremely simple. It is that of the familiar lever that is in equilibrium or balance when it rests on the fulcrum in a level position. The influence of weight is directly dependent upon its distance from the fulcrum. To balance the lever the weight must be distributed so that the turning effect is the same on one side of the fulcrum as on the other. In general, a lighter weight far out on the lever has the same effect as a heavy weight near the fulcrum. The distance of any object from the fulcrum is called the *lever arm*. The *lever arm* multiplied by the *weight* of the object is its turning effect about the fulcrum. This turning effect is known as the *moment*.

Similarly, an aircraft is balanced if it remains level when suspended from an imaginary point. This point is the location of its ideal c.g. An aircraft in balance does not have to be perfectly level, but it must be reasonably close to it. Obtaining this balance is simply a matter of placing loads so that the average arm of the loaded aircraft falls

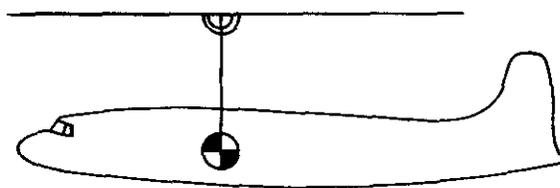


FIGURE 3-1. An airplane suspended from its center of gravity (c.g.).

within the c.g. range. The exact location of the range is specified for each type of airplane.

MATHEMATICAL PROOF

Weight and balance control consists of mathematical proof of the correct weight, balance, and loading within specified limits. These limits are set forth in the specifications for a particular aircraft. The removal or addition of equipment changes the aircraft empty weight and the c.g. The useful load is affected accordingly. The effects these changes produce on the balance of an aircraft must be investigated to determine the effect on the flight characteristics of the aircraft.

WEIGHT AND BALANCE DATA

Weight and balance data can be obtained from the following sources:

- a. The aircraft specifications.
- b. The aircraft operating limitations.
- c. The aircraft flight manual.
- d. The aircraft weight and balance report.

When weight and balance records have been lost and cannot be duplicated from any source, the aircraft must be re-weighed. A new set of weight and balance records must be computed and compiled.

TERMINOLOGY

In the study of weight and balance principles, computation, and control, it is necessary to know the meaning of the terms used. The following terminology is used in the practical application of weight and balance control, and should be thoroughly studied.

The Datum

The datum is an imaginary vertical plane from which all horizontal measurements are taken for balance purposes, with the aircraft in level flight attitude. It is a plane at right angles to the longitudinal axis of the aircraft. For each aircraft make and model, all locations of equipment, tanks, baggage compartments, seats, engines, propellers, etc., are listed in the Aircraft Specification or Type Certificate Data Sheets as being so many inches from the datum. There is no fixed rule for the location of the datum. In most cases it is located on the nose of the aircraft or some point on the aircraft structure itself. In a few cases,

it is located a certain distance forward of the nose section of the aircraft. The manufacturer has the choice of locating the datum where it is most convenient for measurement, locating equipment, and weight-and-balance computation.

The datum location is indicated on most aircraft specifications. On some of the older aircraft, where the datum is not indicated, any convenient datum may be selected. However, once the datum is selected, it must be properly identified so that anyone who reads the figures will have no doubt about the exact datum location. Figure 3-2 shows some datum locations used by manufacturers.

The Arm

The arm is the horizontal distance that an item of equipment is located from the datum. The arm's distance is always given or measured in inches, and, except for a location which might be exactly on the datum (0), it is preceded by the algebraic sign for plus (+) or minus (-). The plus (+) sign indicates a distance aft of the datum and the minus (-) sign indicates a distance forward of the datum. If the manufacturer chooses a datum that is at the most forward location on an aircraft (or some distance forward of the aircraft), all the arms will be plus (+) arms. Location of the datum at any other point on the aircraft will result in some arms being plus (+), or aft of the datum, and some arms minus (-), or forward of the datum.

The arm of each item is usually included in parentheses immediately after the item's name or weight in the specifications for the aircraft, e.g., seat (+23). When such information is not given, it must be obtained by actual measurement. Datum, arm, c.g., and the forward and aft c.g. limits are illustrated in figure 3-3.

The Moment

A moment is the product of a weight multiplied by its arm. The moment of an item about the datum is obtained by multiplying the weight of the item by its horizontal distance from the datum. Likewise, the moment of an item about the c.g. can be computed by multiplying its weight by the horizontal distance from the c.g.

A 20-pound weight located 30 inches from the datum would have a moment of 20×30 or 600 lb.-in. Whether the value of 600 lb.-in. is preceded by a plus (+) or minus (-) sign depends on

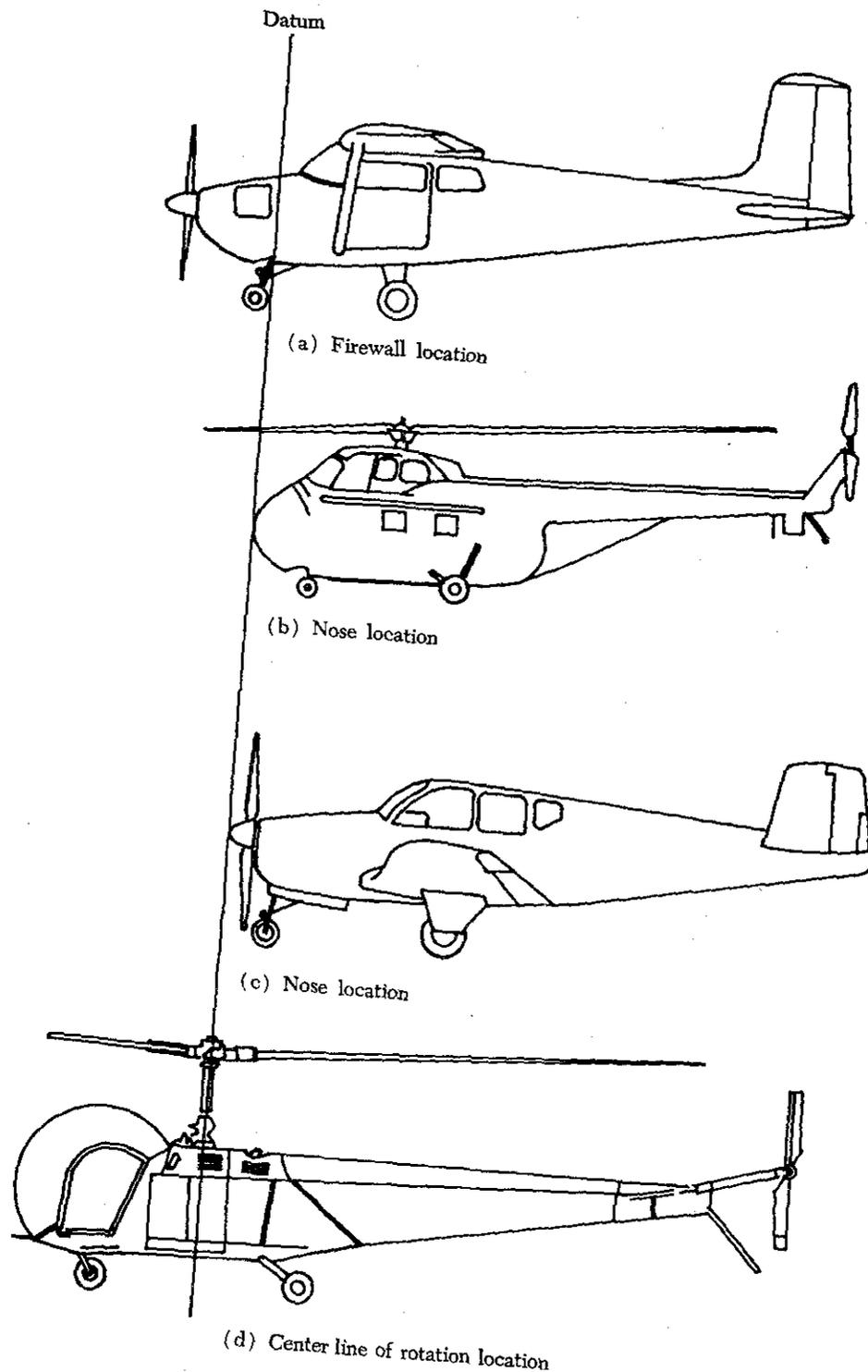


FIGURE 3-2. Various datum locations.

whether the moment is the result of a weight being removed or added and its location in relation to the datum. Any item of weight added to the aircraft either side of the datum is plus weight.

Any weight item removed is a minus weight. When multiplying a weight by an arm, the resulting moment is plus if the signs are alike and minus if the signs are unlike.

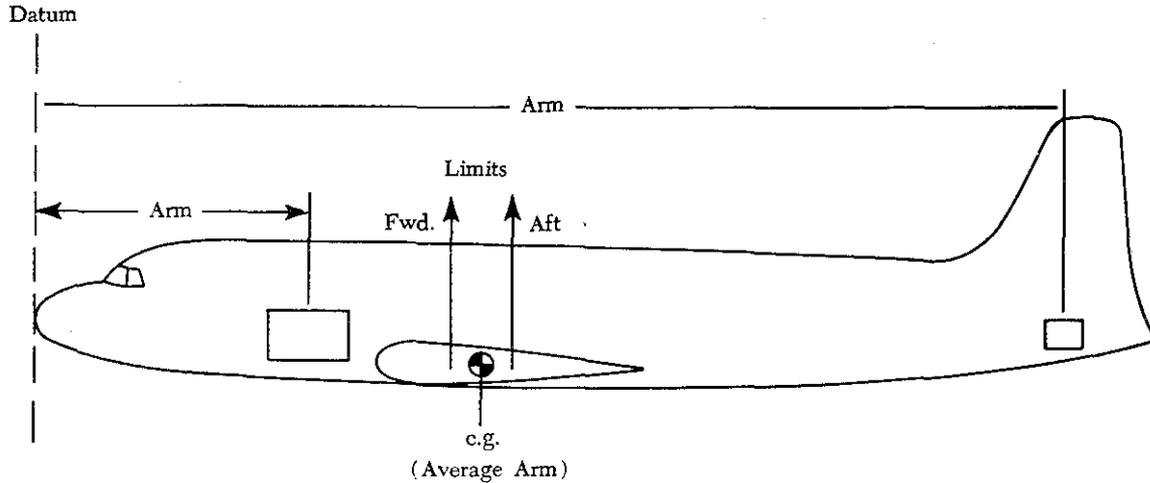


FIGURE 3-3. Datum, arm, c.g., and c.g. limits.

Center of Gravity

The c.g. of an aircraft is a point about which the nose-heavy and tail-heavy moments are exactly equal in magnitude. An aircraft suspended from this point would have no tendency to rotate in either a noseup or nosedown attitude. It is the point about which the weight of an airplane or any object is concentrated.

Maximum Weight

The maximum weight is the maximum authorized weight of the aircraft and its contents, and is indicated in the specifications. For many aircraft there are variations to the maximum allowable weight, depending on the purpose and conditions under which the aircraft is to be flown. For example, a certain aircraft may be allowed a maximum gross weight of 2,750 pounds when flown in the normal category, but when flown in the utility category, the same aircraft's maximum allowable gross weight would be 2,175 pounds.

Empty Weight

The empty weight of an aircraft includes all operating equipment that has a fixed location and is actually installed in the aircraft. It includes the weight of the airframe, powerplant, required equipment, optional or special equipment, fixed ballast, hydraulic fluid, and residual fuel and oil.

Residual fuel and oil are the fluids that will not normally drain out because they are trapped in the fuel lines, oil lines, and tanks. They must be included in the aircraft's empty weight. Infor-

mation regarding residual fluids in aircraft systems which must be included in the empty weight will be indicated in the Aircraft Specification.

Useful Load

The useful load of an aircraft is determined by subtracting the empty weight from the maximum allowable gross weight. For aircraft certificated in both the normal and utility categories, there may be two useful loads listed in the aircraft weight and balance records. An aircraft with an empty weight of 900 pounds will have a useful load of 850 pounds, if the normal category maximum weight is listed as 1,750 pounds. When the aircraft is operated in the utility category, the maximum gross weight may be reduced to 1,500 pounds, with a corresponding decrease in the useful load to 600 pounds. Some aircraft have the same useful load regardless of the category in which they are certificated.

The useful load consists of maximum oil, fuel, passengers, baggage, pilot, copilot, and crewmembers. A reduction in the weight of an item, where possible, may be necessary to remain within the maximum weight allowed for the category in which an aircraft is operating. Determining the distribution of these weights is called a weight check.

Empty Weight Center of Gravity

The empty weight c.g., abbreviated EWCG, is the c.g. of an aircraft in its empty weight condition. It is an essential part of the weight and

balance record of the aircraft. It has no usefulness in itself, but serves as a basis for other computations and not as an indication of what the loaded c.g. will be. The EWCG is computed at the time of weighing, using formulas established for tailwheel- and nosewheel-type aircraft.

Empty Weight Center of Gravity Range

The EWCG range is an allowable variation of travel within the c.g. limits. When the EWCG of the aircraft falls within this range, it is impossible to exceed the EWCG limits using standard specification loading arrangements. Not all aircraft have this range indicated on the Aircraft Specifications or Type Certificate Data Sheets. Where it is indicated, the range is valid only as long as the aircraft is loaded according to the standard specification. The installation of items not listed in the specification will not permit use of this range.

Operating Center of Gravity Range

The operating c.g. range is the distance between the forward and rearward c.g. limits indicated in the pertinent Aircraft Specification or Type Certificate Data Sheets. These limits, determined at the time of design and manufacture, are the extreme loaded c.g. positions allowable within the applicable regulations controlling the design of the aircraft. These limits are shown in either percent of MAC (mean aerodynamic chord) or inches from the datum of the aircraft.

The loaded aircraft c.g. location must remain within these limits at all times. Accordingly, detailed instructions for determining load distribution are provided on placards, loading charts, and load adjusters.

Mean Aerodynamic Chord

The MAC is the mean average chord of the wing. An airfoil section is a cross section of a wing from leading edge to trailing edge. A chord is usually defined as an imaginary straight line drawn parallel to the airfoil through the leading and trailing edges of the section. The MAC of a constant chord wing would be the same as the actual chord of the wing. Any departure from a rectangular wing plan form will affect the length of the MAC and the resulting distance from the MAC leading edge to the aircraft wing leading edge. Figure 3-4 shows the MAC for a sweptwing aircraft.

The aircraft c.g. is usually placed at the maximum forward position of the center of pressure on the MAC to obtain the desired stability. Because of the relationship between the c.g. location and the moments produced by aerodynamic forces, the greatest of which is lift, the c.g. location is generally expressed with respect to the wing. This is done by specifying c.g. in percent of the wing's MAC.

The location of the MAC, in relation to the datum, is given in the Aircraft Specifications or Type Certificate Data Sheets, the weight and balance report, or the aircraft flight manual. Compute the c.g. location in percent of MAC as follows:

- (1) Find the difference between the distance to the empty weight c.g. location from the datum and the distance to the leading edge of MAC from the datum.
- (2) Divide the difference by the length of the MAC.
- (3) Multiply the answer by 100.
- (4) The final answer is then expressed in percent.

An example problem that utilizes the equation for computing percent of MAC is shown in figure 3-5.

Aircraft Leveling Means

Reference points are provided for leveling the aircraft on the ground. They are designated by the manufacturer and are indicated in the pertinent Aircraft Specifications. The most common leveling procedure is to place a spirit level at designated points on the aircraft structure. Some aircraft have special leveling scales built into the airframe structure. The scale is used with a plumb bob to level the aircraft longitudinally and laterally.

Weighing Points

In weighing an aircraft, the point on the scale at which the weight is concentrated is called the weighing point. When weighing light- to medium-weight land planes, the wheels are usually placed on the scales. This means that the weighing point is, in effect, the same location obtained by extending a vertical line through the center line of the axle and onto the scale.

Other structural locations capable of supporting the aircraft, such as jack pads on the main spar,

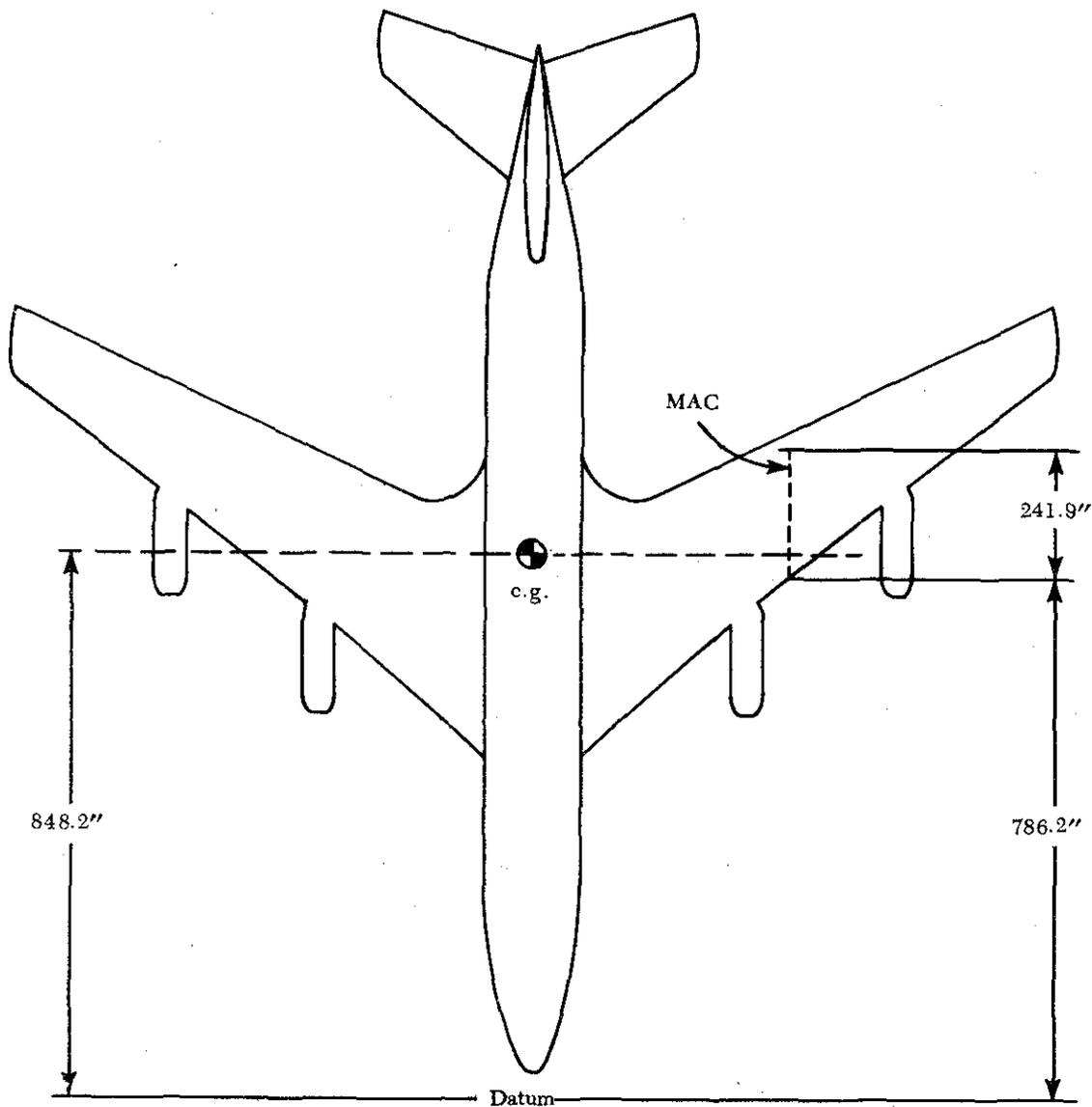


FIGURE 3-4. The c.g. shown in relation to MAC.

may also be used if the aircraft weight is resting on the jack pads. The weighing points should be clearly indicated in the weight and balance report.

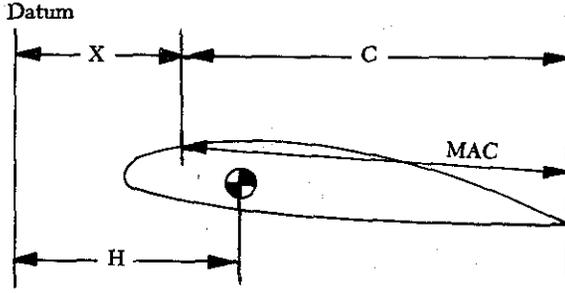
Zero Fuel Weight

The zero fuel weight is the maximum allowable weight of a loaded aircraft without fuel. Included in the zero fuel weight is the weight of cargo, passengers, and crew. All weights in excess of the zero fuel weight must consist of usable fuel.

Minimum Fuel

The term "minimum fuel" should not be interpreted to mean the minimum amount of fuel required to fly an aircraft. Minimum fuel, as it applies to weight and balance, is the amount of fuel that must be shown on the weight and balance report when the airplane is loaded for an extreme-condition check.

The minimum fuel load for a small aircraft with a reciprocating engine for balance purposes is based on engine horsepower. It is calculated in the METO (maximum except take-off) horsepower and



H = Distance from the datum to the EWCG = 170 inches.
 X = Distance from the datum to the MAC leading edge = 150 inches.
 C = Length of MAC = 80 inches.

$$\text{e.g. in \% of MAC} = \frac{H - X}{C} \times 100$$

$$\% \text{ of MAC} = \frac{170 - 150}{80} \times 100 =$$

$$\frac{20}{80} \times 100 = 25\%$$

FIGURE 3-5. Finding percent of MAC.

is the figure used when the fuel load must be reduced to obtain the most critical loading on the c.g. limit being investigated. Either of 2 formulas may be used.

Formula 1:

Minimum fuel = $\frac{1}{12}$ gallons per horsepower.
 $\text{hp} \times \frac{1}{12} \times 6 \text{ lb.}$
 $1200 \times \frac{1}{12} \times 6 = 1200 \times \frac{1}{12} \times 6 = 600 \text{ lb. fuel.}$

Formula 2:

Minimum fuel = $\frac{1}{2}$ lb. per engine horsepower.
 $\text{hp} \times \frac{1}{2} = \text{minimum fuel.}$
 $1200 \times \frac{1}{2} = 600 \text{ lb. fuel.}$

This will be the minimum pounds of fuel required for the forward or rearward weight check.

For turbine-engine powered aircraft, the minimum fuel load is specified by the aircraft manufacturer.

The fuel tank location in relation to the c.g. limit affected by the computation determines the use of minimum fuel. For example, when a forward weight check is performed, if the fuel tanks are located forward of the forward c.g. limit, they are assumed to be full. If they are located aft of the forward c.g. limit, they are assumed to be empty. If the minimum fuel required for a particular aircraft exceeds the capacity of the tanks located forward of the forward c.g. limit, the excess fuel must be loaded in the tanks that are aft of the forward c.g. limit. When a rearward weight check is conducted, the fuel loading conditions are opposite to those used for the forward check.

Full Oil

Full oil is the quantity of oil shown as oil capacity in the Aircraft Specifications. When weighing an aircraft, the oil tank may either contain the number of gallons of oil specified or be drained. When an aircraft with full oil tanks is weighed, the weight of the oil must be subtracted from the recorded readings to arrive at the actual empty weight. The weight and balance report must show whether weights include full oil or if the oil tanks were drained.

Tare Weight

Tare includes the weight of all extra items, such as jacks, blocks, and chocks on the weighing scale platform, except that of the item being weighed. The weight of these items, when included in the scale reading, is deducted to obtain the actual weight of the aircraft.

AIRCRAFT WEIGHING PROCEDURE

Before beginning a study of aircraft weighing procedure or attempting the actual weighing of an aircraft, it is necessary to become familiar with the weight and balance information in the applicable Aircraft Specification or Type Certificate Data Sheet.

The specification for Taylorcraft, model BC and BCS airplanes, illustrated in figure 3-6 has been reproduced in its entirety. A few of the items need explaining; the rest are self-explanatory.

The designation 2 PCLM is read "2-place, closed land monoplane" and indicates that the airplane seats two persons, has an enclosed cockpit, can be operated from the solid part of the earth's surface, and has only one wing. Two PCSM indicates that the airplane is a "2-place, closed sea monoplane." It should be noted that the c.g. range, EWCG range, and the maximum weight are different for the landplane and the seaplane. The location of the seats indicates a side-by-side arrangement. The datum and the leveling means are shown in the portion of the specification that is pertinent to all models. Since the datum and the leveling means are directly connected to weight and balance, they would be among the first items referred to in planning the weighing operation.

Although the location or arrangement of the

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

A-696
Revision 16
TAYLORCRAFT
BCS12-D
BC12-D1
BCS12-D1
BC12D-85
BCS12D-85
BC12D-4-85
BCS12D-4-85
BC12-D
9 September 1969

BC
BCS
BC-65
BCS-65
BC12-65 (Army L-2H)
BCS12-65
BC12-D

AIRCRAFT SPECIFICATION NO. A-696

Type Certificate Holder. Taylorcraft Aviation Corporation
104 Prospect Street
Alliance, Ohio 44601

I—Model BC, 2 PCLM, Approved August 24, 1938; Model BCS, 2 PCSM, Approved April 5, 1939

Engine. Continental A-50-1 (see item 114(a) for optional engines)

Fuel. 73 min. grade aviation gasoline

Engine Limits. For all operations, 1900 r.p.m. (50 hp.)

Propeller Limits. Diameter: Maximum 83 in.

Airspeed Limits. (True Ind.)
Landplane: Level flight or climb 105 m.p.h. (91 knots)
Glide or dive 131 m.p.h. (114 knots)
Seaplane: Level flight or climb 95 m.p.h. (83 knots)
Glide or dive 129 m.p.h. (112 knots)

Center of Gravity (C.G.) Range. Landplane: (+14.5) to (+19.7)
Seaplane: (+15.1) to (+19.4)

Empty Weight C.G. Range. Landplane: (+15.3) to (+18.5)
Seaplane: (+15.9) to (+18.3)
When empty weight C.G. falls within pertinent range, computation of critical for and aft C.G. positions is unnecessary. Ranges are not valid for non-standard arrangements.

Maximum Weight. Landplane: 1100 lb. (S/N 1407 and up are eligible at 1150 lb.)
Seaplane: 1228 lb.

Number of Seats. 2 (+23)

Maximum Baggage. 30 lb. (+40)

Fuel Capacity. 12 gal. (-9). See item 115 for auxiliary tank.

Oil Capacity. 4 quart. (-21)

Control Surface Movements. Elevators: Up 25° Down 27°
Rudders: Right 26° Left 26°
Ailerons: (Not available)

Serial No. Eligible. 1001 and up

Required Equipment. Landplane: 1 or 4, 104, 202, 203, 210(a), 401
Seaplane: 1 or 4, 104, 205, 401

Specifications Pertinent to All Models.

Datum. Leading edge of wing

Leveling Means. Upper surface of horizontal stabilizer

Certification Basis. Part 04 of the Civil Air Regulations effective as amended to May 1, 1938. Type Certificate No. 696 issued.

Production Basis. None. Prior to original certification, an FAA representative must perform a detailed inspection for workmanship, materials and conformity with the approved technical data, and a check of the flight characteristics.

FIGURE 3-6. A typical aircraft specification.

landing gear is not shown in figure 3-6, this information is given in the Aircraft Specification or Type Certificate Data Sheets and the maintenance manual. The location of the wheels has important significance, since this can be used as a doublecheck against actual measurements taken at the time of weighing.

Weighing an Aircraft

Weighing an aircraft is a very important and exacting phase of aircraft maintenance and must be carried out with accuracy and good workmanship. Thoughtful preparation saves time and prevents mistakes.

To begin, assemble all the necessary equipment, such as:

1. Scales, hoisting equipment, jacks, and leveling equipment.
2. Blocks, chocks, or sandbags for holding the airplane on the scales.
3. Straightedge, spirit level, plumb bobs, chalk line, and a measuring tape.
4. Applicable Aircraft Specifications and weight and balance computation forms.

If possible, aircraft should be weighed in a closed building where there are no air currents to cause incorrect scale readings. An outside weighing is permissible if wind and moisture are negligible.

Prepare Aircraft For Weighing

Drain the fuel system until the quantity indication reads zero, or empty, with the aircraft in a level attitude. If any fuel is left in the tanks, the aircraft will weigh more, and all later calculations for useful load and balance will be affected. Only trapped or unusable fuel (residual fuel) is considered part of the aircraft empty weight. Fuel tank caps should be on the tanks or placed as close as possible to their correct locations, so that the weight distribution will be correct.

In special cases, the aircraft may be weighed with the fuel tanks full, provided a means of determining the exact weight of the fuel is available. Consult the aircraft manufacturer's instructions to determine whether a particular model aircraft should be weighed with full fuel or with the fuel drained.

If possible, drain all engine oil from the oil tanks. The system should be drained with all drain valves open. Under these conditions, the amount of oil remaining in the oil tank, lines, and

engine is termed residual oil and is included in the empty weight. If impractical to drain, the oil tanks should be completely filled.

The position of such items as spoilers, slats, flaps, and helicopter rotor systems is an important factor when weighing an aircraft. Always refer to the manufacturer's instructions for the proper position of these items.

Unless otherwise noted in the Aircraft Specifications or manufacturer's instructions, hydraulic reservoirs and systems should be filled; drinking and washing water reservoirs and lavatory tanks should be drained; and constant-speed-drive oil tanks should be filled.

Inspect the aircraft to see that all items included in the certificated empty weight are installed in the proper location. Remove items that are not regularly carried in flight. Also look in the baggage compartments to make sure they are empty.

Replace all inspection plates, oil and fuel tank caps, junction box covers, cowling, doors, emergency exits, and other parts that have been removed. All doors, windows, and sliding canopies should be in their normal flight position. Remove excessive dirt, oil, grease, and moisture from the aircraft.

Properly calibrate, zero, and use the weighing scales in accordance with the manufacturer's instructions.

Some aircraft are not weighed with the wheels on the scales, but are weighed with the scales placed either at the jacking points or at special weighing points. Regardless of what provisions are made for placing the aircraft on the scales or jacks, be careful to prevent it from falling or rolling off, thereby damaging the aircraft and equipment. When weighing an aircraft with the wheels placed on the scales, release the brakes to reduce the possibility of incorrect readings caused by side loads on the scales.

All aircraft have leveling points or lugs, and care must be taken to level the aircraft, especially along the longitudinal axis. With light, fixed-wing airplanes, the lateral level is not as critical as it is with heavier airplanes. However, a reasonable effort should be made to level the light airplanes around the lateral axis. Accuracy in leveling all aircraft longitudinally cannot be overemphasized.

Measurements

The distance from the datum to the main weighing point centerline, and the distance from

the main weighing point centerline to the tail (or nose) weighing point centerline must be known to determine the c.g. relative to the main weighing point and the datum.

An example of main weighing point to datum and main weighing point to tail weighing point is shown in figure 3-7. See figure 3-8 for an example of main weighing point to datum and main weighing point to nosewheel measurements.

These distances may be calculated using information from the Aircraft Specifications or Type Certificate Data Sheets. However, it will often be necessary to determine them by actual measurement.

After the aircraft has been placed on the scales (figure 3-9) and leveled, hang plumb bobs from the datum, the main weighing point, and the tail or nose weighing point so that the points of the plumb bobs touch the floor. Make a chalk mark on the floor at the points of contact. If desired, a chalk line may be drawn connecting the chalk marks. This will make a clear pattern of the weighing point distances and their relation to the datum.

Record the weights indicated on each of the scales and make the necessary measurements while the aircraft is still level. After all weights

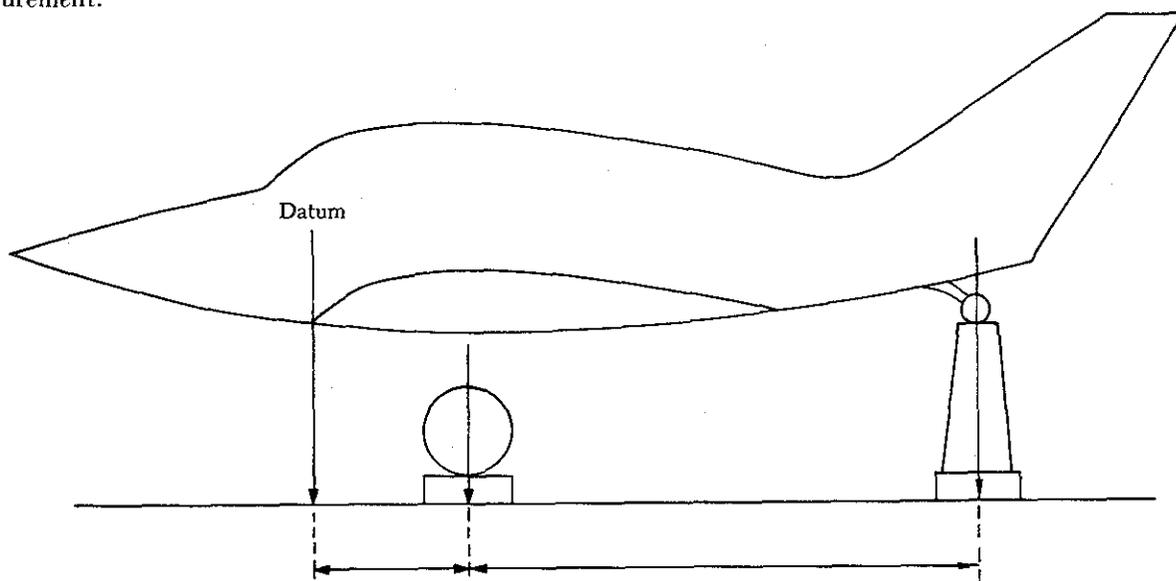


FIGURE 3-7. Main weighing point to datum and main weighing point to tail weighing point.

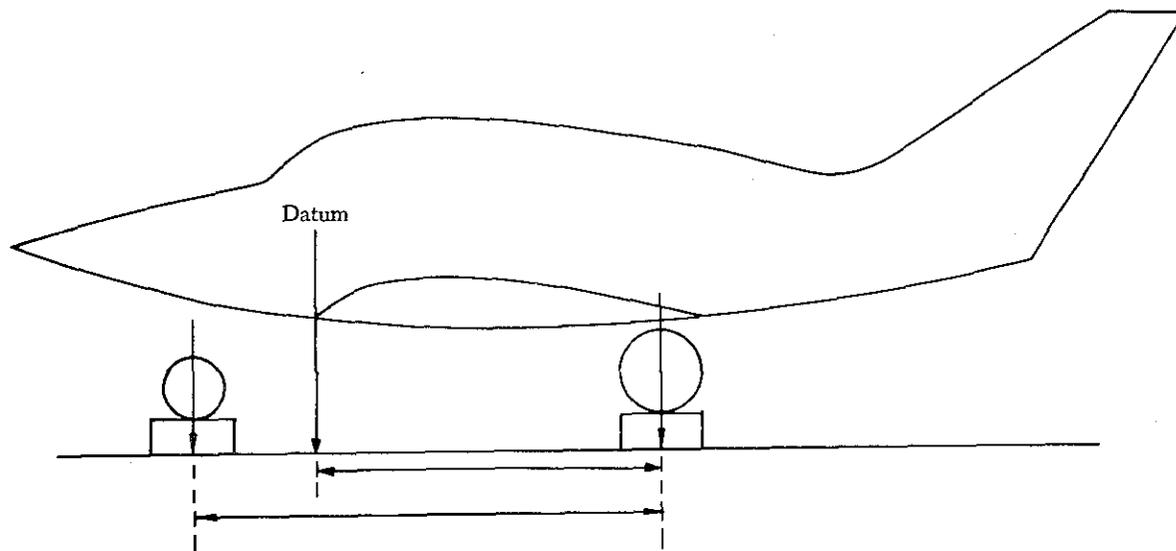


FIGURE 3-8. Main weighing point to datum and main weighing point to nose weighing point.

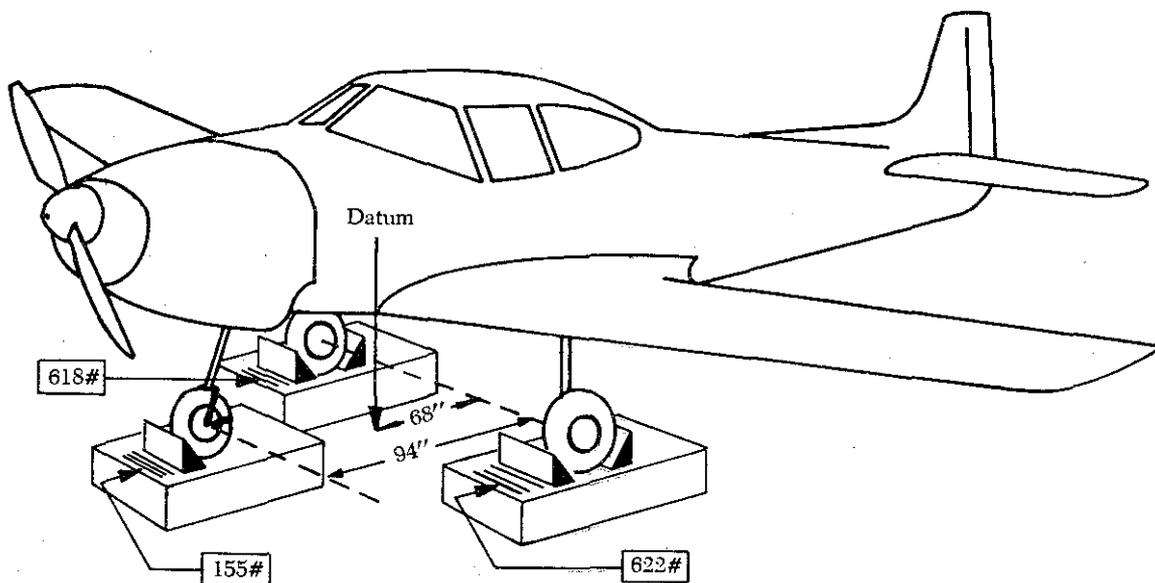


FIGURE 3-9. Weighing an aircraft using platform scales.

and measurements are obtained and recorded, the aircraft may be removed from the scales. Weigh the tare and deduct its weight from the scale reading at each respective weighing point where tare is involved.

Balance Computation

To obtain gross weight and the c.g. location of the loaded airplane, first determine the empty weight and the EWCG location. When these are known, it is easy to compute the effect of fuel, crew, passengers, cargo, and expendable weight as they are added. This is done by adding all the weights and moments of these additional items and re-calculating the c.g. for the loaded airplane.

The scale readings and measurements recorded on the sample form in figure 3-10 form the basis for the examples of computing the empty weight and the empty weight c.g.

Empty Weight

The empty weight of the aircraft is determined by adding the net weight on each weighing point. The net weight is the actual scale reading, less the tare weight.

<i>Weighing scale point</i>	<i>Scale reading (lbs.)</i>	<i>Tare (lbs.)</i>	<i>Net weight (lbs.)</i>
Left main wheel	622.00	-5.00	617.00
Right main wheel	618.00	-4.00	614.00
Nosewheel	155.00	-3.00	152.00
Total			1,383.00

This gives the aircraft weight as weighed.

Empty Weight C.G.

The c.g. location is found through the progressive use of two formulas. First calculate the total moments using the following formulas:

$$\text{Moment} = \text{Arm} \times \text{Weight}$$

<i>Weight point</i>	<i>Net weight (lbs.)</i>	<i>Arm (in.)</i>	<i>Moment (lb.-in.)</i>
Left main wheel	617.0	× 68"	= 41,956.0
Right main wheel	614.0	× 68"	= 41,752.0
Nosewheel	152.0	× -26"	= -3,952.0
	1,383.0		79,756.0

WEIGHING FORM

MAKE Rotary MODEL A SERIAL 0242 N 411

DATUM LOCATION Leading edge of wing at root

Aircraft weighed with full oil.

1. Main weighing point is located (....." forward) (+68" aft) of datum.
2. Tail or nose weighing point is located (-26" forward) (+....." aft) of datum.

	Weighing Point	Scale Reading	- Tare	= Net Weight	× Arm	= Moment
3.	Left Main Wheel	622.00	-5.00	617.00	68"	41,956.00
4.	Right Main Wheel	618.00	-4.00	614.00	68"	41,752.00
5.	Sub-Total	1,240.00	-9.00	1,231.00	68"	83,708.00
6.	Tail or Nose Wheel	155.00	-3.00	152.00	-26"	-3,952.00
7.	Total as Weighed	1,395.00	-12.00	1,383.00	57.67	79,756.00

Space for listing of Items when Aircraft is not Weighed Empty.

	Item	Net Weight	Arm	Moment
8.	Oil - 8 gallons @ 7.5 p/p/g	-80.00	-30.00	1,800.00
9.	Aircraft Empty Weight & c.g.	1,323.00	61.64"	81,556.00

Maximum Allowable Gross Weight 1,773 pounds

Useful Load 450 pounds

Computed by: Frank A. Adams

A & P Number: 1386968

FIGURE 3-10. Sample weighing form.

then divide the sum of the moments by the total weights involved:

$$\text{c.g.} = \frac{\text{Total moment}}{\text{Total weight}} = \frac{79,756.0}{1,383}$$

$$= 57.67 \text{ in.}$$

Consequently, the c.g., as weighed, is 57.67 in. from the datum.

Since the aircraft was weighed with the oil tank full, it is necessary to remove the oil to obtain the empty weight and empty weight c.g.

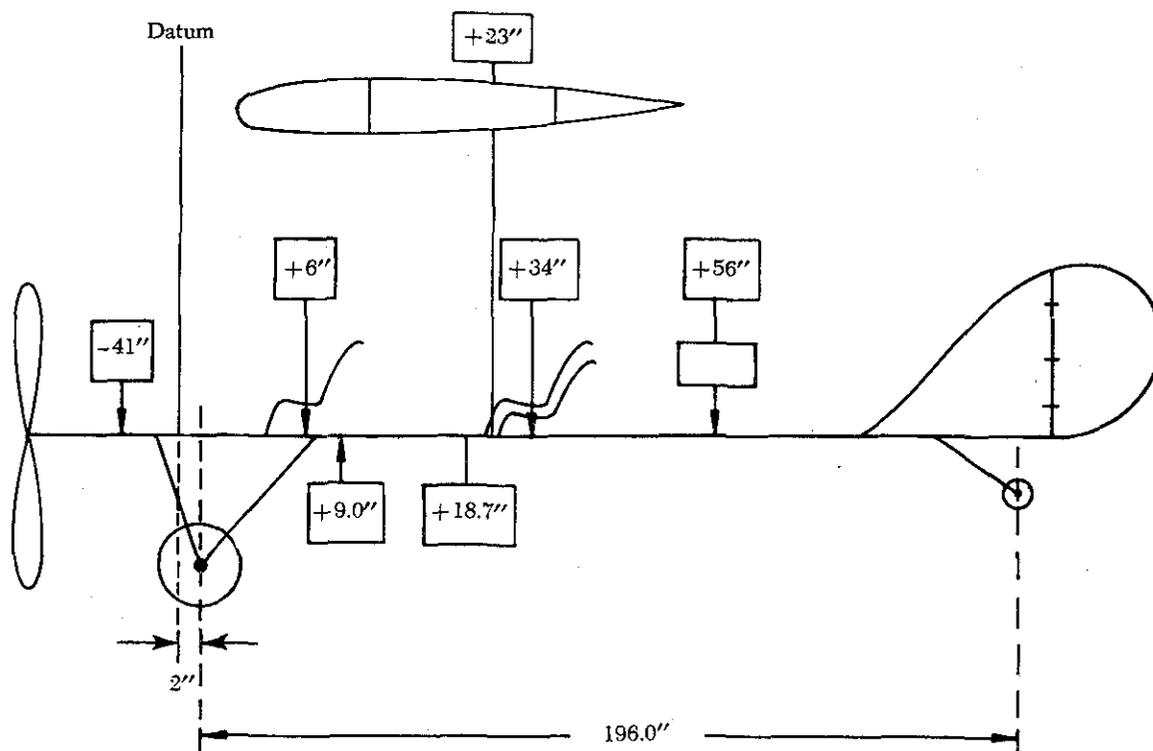
Item	Net weight (lbs.)	Arm (in.)	Moment (lb.-in.)
Acft. total as weighed	1,383.0	57.67	79,756.0
Less oil, 8 gallons, @ 7.5 lbs. per gallon	-60.0	-30.00	1,800.0
Acft. empty weight and moment	1,323.0		81,556.0

Again using the formula:

$$\text{c.g.} = \frac{\text{Total moment}}{\text{Total weight}} = \frac{81,556.0}{1,323}$$

$$= 61.64 \text{ in.}$$

The EWCG is located 61.64 in. aft of the datum.



Tail wheel weight = 50 lbs.

Tail wheel arm = 198.0"

Empty weight (without oil) = 950 lbs.

Datum location = leading edge of wing.

Engine = 100 hp.

CG range = (+9.0") to (+18.7").

Fuel capacity = 40 gal @ +23".

Number of seats = 3 (one @ +6" and two @ +34").

Maximum gross weight = 1775 lbs.

Oil capacity = 8 qts @ -41".

Maximum baggage = 50 lbs @ +56".

Note: (This airplane can be flown from either the front or rear seat.)

FIGURE 3-11. Schematic diagram for forward weight and balance check.

The maximum allowable gross weight as shown in the Aircraft Specifications is 1,733 pounds. By subtracting the aircraft empty weight from this figure, the useful load is determined to be 450 pounds.

WEIGHT AND BALANCE EXTREME CONDITIONS

The weight and balance extreme conditions represent the maximum forward and rearward c.g. position for the aircraft.

An aircraft has certain fixed points, fore and aft, beyond which the c.g. should not be permitted at any time during flight. A check should be made to ensure that the c.g. will not shift out of limits

when crew, passengers, cargo, and expendable weights are added or removed. If the limits are exceeded and the aircraft is flown in this condition, it may lead to insufficient stability, with resulting difficulty in controlling the aircraft.

Adverse loading checks are a deliberate attempt to load an aircraft in a manner that will create the most critical balance condition and still remain within the design c.g. limits of the aircraft.

It should be noted that when the EWCG falls within the EWCG range, it is unnecessary to perform a forward or rearward weight and balance check. In other words, it is impossible to load the aircraft to exceed the c.g. limits, provided standard loading and seating arrangements are used.

Forward Weight and Balance Check

To make this check, the following information is needed:

1. The weight, arm, and moment of the empty aircraft.
2. The maximum weights, arms, and moments of the items of useful load that are located ahead of the forward c.g. limit.
3. The minimum weights, arms, and moments of the items of useful load that are located aft of the forward c.g. limit.

The example shown in figure 3-11 presents one method of conducting an extreme-condition check. This method makes it easy to visualize exactly where the weights of various loading arrangements are distributed and how they affect c.g. location.

Using the data given in figure 3-11, determine if the airplane can be loaded to cause the c.g. to go beyond its limits.

FIRST STEP: Load the airplane as follows:

- Oil—8 qts. @ -41 in. = (15.0 lbs.) (-41 in.).
- Pilot—170 lbs. @ +6 in. = (170.0 lbs.) (+6 in.).
- Fuel, minimum—50 lbs. @ +23 in. = (50.0 lbs.) (+23 in.).
- No passengers.
- No baggage.

Fill any fuel tanks which are ahead of the forward limit. If the fuel tanks are to the rear of the forward limit, use the minimum required amount of fuel.

SECOND STEP: Total all weights and moments.

Item	Weight (lbs.)	Arm (in.)	Moments (lb.-in.)
Acft. EW	950.0	+12.3	+11,685.0
Oil	15.0	-41.0	- 615.0
Pilot	170.0	+ 6.0	+ 1,020.0
Fuel (min.)	50.0	+23.0	+ 1,150.0
Total	1,185.0		13,240.0

The above figures require careful consideration. Notice that each weight is multiplied by its arm to obtain its moment. All the weights are added to obtain 1,185 lbs., the total weight. However, when adding the moments, all the plus moments are added:

$$\begin{array}{r}
 11,685.0 \\
 1,020.0 \\
 1,150.0 \\
 \hline
 13,855.0
 \end{array}$$

The minus moment of -615.0 is subtracted from the sum of the plus moments:

$$\begin{array}{r}
 13,855.0 \\
 - 615.0 \\
 \hline
 13,240.0
 \end{array}$$

THIRD STEP: Find the most forward c.g. position by dividing the total moments by the total weight.

$$\frac{13,240.0}{1,185} = 11.17 \text{ in.}$$

Since the total moment is plus, the answer must be plus. Therefore, the forward extreme position of the c.g. is located at 11.17 aft of the datum.

The forward c.g. limit for this example airplane is +9.0 in. aft of the datum; therefore, it is easy to see that it can be safely flown with this loading arrangement.

Rearward Weight and Balance Check

To establish that neither the maximum weight nor the rearward c.g. limit is exceeded, the following information is needed:

1. The weight, arm, and moment of the empty aircraft.
2. The maximum weights, arms, and moments of the items of useful load that are located aft of the rearward c.g. limit.
3. The minimum weights, arms, and moments of the items of useful load that are located ahead of the rearward c.g. limit.

The most rearward c.g. position is found by repeating the three steps that were followed in making the most forward c.g. check, except in this case the airplane is loaded so that it will be tail-heavy.

FIRST STEP: Load the airplane in a manner that will make it most tail-heavy.

- Oil—8 qts. @ -41 in. = (15.0 lbs.) (-41 in.).
- Pilot—170 lbs. @ +6 in. = (170.0 lbs.) (+6 in.).
- Fuel (max.)—40 gals. @ +23 in. = (240.0 lbs.) (+23 in.).
- Passengers—two @ 170 lbs. each = 340 lbs. @ +34 in. = (340 lbs.) (+34 in.).
- Baggage (max.)—50 lbs. @ +56 in. = (50 lbs.) (+56 in.).

Fill any fuel tanks which are aft of the rear limit. If the fuel tanks are forward of the rear limit, use the minimum required amount of fuel.

SECOND STEP: Total all weights and moments as shown here:

Item	Weight (lbs.)	Arm (in.)	Moments (lb.-in.)
Acft. EW	950.0	+12.3	+11,685.0
Oil	15.0	-41.0	- 615.0
Pilot	170.0	+ 6.0	+ 1,020.0
Fuel (max.)	240.0	+23.0	+ 5,520.0
Passengers (two)	340.0	+34.0	+11,560.0
Baggage (max.)	50.0	+56.0	+ 2,800.0
Total	1,765.0		31,970.0

THIRD STEP: Find the most rearward c.g. position by dividing the total moments by the total weight.

Most rearward c.g. when loaded as shown in figure 3-11:

$$\frac{31,970.0}{1,765} = 18.11 \text{ in.}$$

The rearward c.g. limit for this example airplane is +18.7 in. aft of the datum; therefore, it can be flown safely with this loading arrangement.

INSTALLATION OF BALLAST

Ballast is used in an aircraft to attain the desired c.g. balance. It is usually located as far aft or as far forward as possible to bring the c.g. within limits using a minimum amount of weight. Ballast that is installed to compensate for the removal or installation of equipment items and that is to remain in the aircraft for long periods is called permanent ballast. It is generally lead bars or plates bolted to the aircraft structure. It may be painted red and placarded: **PERMANENT BALLAST—DO NOT REMOVE**. In most cases, the installation of permanent ballast results in an increase in the aircraft empty weight.

Temporary ballast, or removable ballast, is used to meet certain loading conditions that may vary from time to time. It generally takes the form of lead shot bags, sand bags, or other weight items that are not permanently installed. Temporary ballast should be placarded: **BALLAST — LBS. REMOVAL REQUIRES WEIGHT AND BALANCE CHECK**. The baggage compartment is usually the most convenient location for temporary ballast.

The places for carrying ballast should be properly designed, installed, and plainly marked. The aircraft operation manual must include instructions regarding the proper placement of the re-

movable ballast under all loading conditions for which such ballast is necessary.

Controlling c.g. Position With Ballast

Figure 3-12 shows an example aircraft whose c.g. exceeds the forward c.g. limit under certain loading conditions. The forward weight and balance check proves that with only the pilot and minimum fuel aboard, the forward c.g. is exceeded.

Most forward c.g. check

Item	Weight (lbs.)	Arm (in.)	Moments (lb.-in.)
Acft. EW	1,600.0	+15.6	+24,960.0
Oil	22.5	-22.0	- 495.0
Fuel (min.)	115.0	+18.0	+ 2,070.0
Pilot	170.0	+10.0	+ 1,700.0
Total	1,907.5		+28,235.0

$$\text{Most forward c.g.} = \frac{\text{Total moment}}{\text{Total weight}}$$

$$= \frac{28,235}{1,907.5} = 14.8 \text{ in.}$$

Without ballast placed somewhere aft to bring the c.g. within the designated limits of +16.5 in. to +20.0 in., the aircraft is unsafe to fly when loaded with the pilot and minimum fuel. The problem of determining how many pounds of ballast are needed to move the c.g. within the approved limits can be solved by using the following formula:

Ballast weight needed:

$$\frac{(\text{Weight of acft as loaded}) (\text{Distance out of limits})}{\text{Arm from variable weight location to limit affected}}$$

Inserting in the formula the applicable values:

$$\text{Weight of the aircraft as loaded} = 1907.5$$

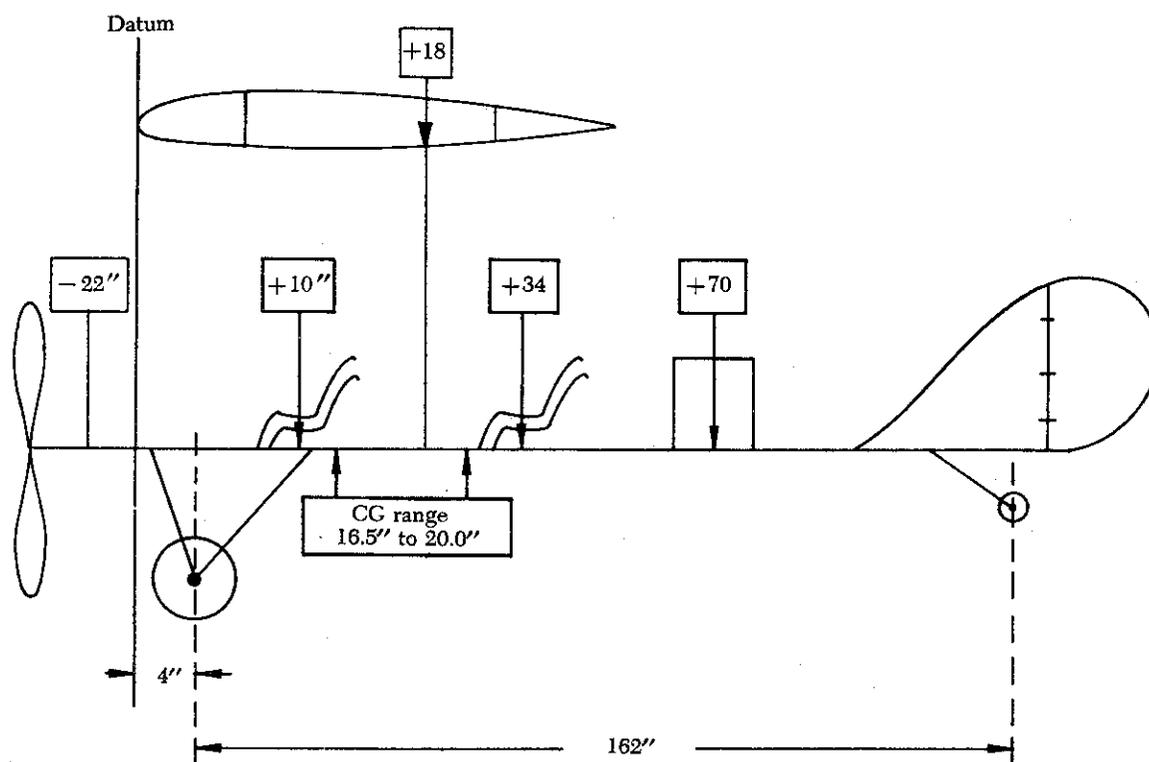
$$\text{Distance out of limit} = +1.7 \text{ in.}$$

$$\text{Arm from variable weight location to the limit affected} = 53.5 \text{ in.}$$

We obtain the following:

$$\frac{(1907.5) (1.7)}{53.5} = 60.6 \text{ lbs., ballast weight needed in the baggage compartment.}$$

When the mathematical computation ends in a fractional pound, use the next higher whole pound as the actual ballast weight. Consequently, 61.0 pounds must be placed in the baggage compartment to bring the c.g. safely within the c.g. range.



Tail wheel arm = 166".

Tail wheel weight = 115 lbs.

CG range = (+16.5") to (+20.0")

Fuel capacity = 38 gal @ 18" (19 gal. in each wing)

Maximum baggage = 100 lbs @ 70"

Maximum gross weight = 2620 lbs.

A/C EW (without oil) = 1600 lbs.

Datum = leading edge of wing.

Engine = 230 hp.

Oil capacity = 12 qts @ -22".

Number of seats = 4 (two @ +10" and two @ +34").

Note: Flight controls in front seat only.

FIGURE 3-12. Example aircraft whose c.g. exceeds the forward c.g. limit.

A final forward weight and balance check should be made to prove that by adding 61.0 pounds of ballast in the baggage compartment, this aircraft could be safely flown with minimum fuel aboard. Place a placard in the cockpit in a conspicuous place for the pilot, or anyone concerned, to see. The placard should read: FOR SOLO FLIGHT CARRY A MINIMUM OF 61.0 POUNDS IN BAGGAGE COMPARTMENT.

Maximum Load Conditions

A rearward weight and balance check will determine whether the airplane shown in figure 3-12 can be flown safely when fully loaded without exceeding the aft c.g. limit or its maximum gross weight.

Most Rearward c.g. check.

Item	Weight (lbs.)	Arm (in.)	Moments (lb.-in.)
Acft. EW	1,600.0	+15.6	24,960.0
Oil	22.5	-22.0	- 495.0
Fuel (max.)	228.0	+18.0	4,104.0
Pilot	170.0	+10.0	1,700.0
Passenger	170.0	+10.0	1,700.0
Passengers (two)	340.0	+34.0	11,560.0
Baggage (max.)	100.0	+10.0	7,000.0
Total	2,630.5		50,529.0

$$\text{Most rearward c.g.} = \frac{\text{Total moments}}{\text{Total weight}}$$

$$= \frac{50,529.0}{2,630.5} = 19.21 \text{ in.}$$

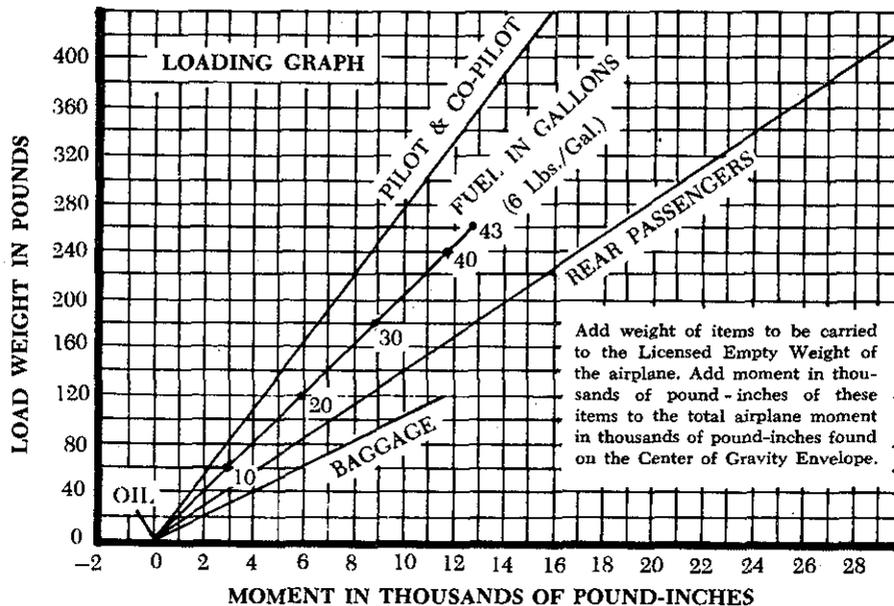


FIGURE 3-13. Typical loading graph.

The c.g. is well within the c.g. range when fully loaded; however, the maximum allowable gross weight is exceeded by 10.5 pounds. In this case a number of alternatives are available to remedy this overloaded condition without appreciably reducing the aircraft payload or flight range, as follows:

Alternative No. 1—reduce baggage by 10.5 lbs.

Alternative No. 2—reduce fuel by 10.5 lbs., or 1.75 gals.

Alternative No. 3—reduce passenger load by one passenger.

Each alternative listed will require a placard stating the loading arrangement by which the gross weight and c.g. will be retained within their designated limits. Compute a new c.g. position for each alternate loading arrangement.

LOADING GRAPHS AND C.G. ENVELOPES

The weight and balance computation system, commonly called the loading graph and c.g. envelope system, is an excellent and rapid method for determining the c.g. location for various loading arrangements. This method can be applied to any make and model of aircraft.

Aircraft manufacturers using this method of weight and balance computation prepare graphs similar to those shown in figure 3-13 and 3-14

for each make and model aircraft at the time of original certification. The graphs become a permanent part of the aircraft records. Along with the graphs are the data for the empty weight arm and moment (index number) for that particular make and model aircraft.

The loading graph illustrated in figure 3-13 is used to determine the index number of any item or weight that may be involved in loading the aircraft. To use this graph, find the point on the vertical scale that represents the known weight. Project a horizontal line to the point where it intersects the proper diagonal weight line (i.e., pilot, copilot, baggage, etc.). From the point of intersection, read straight downward to the horizontal scale to find the moment or index number.

After the moment for each item of weight has been determined, all weights are added and all moments are added. With knowledge of the total weight and moment, project a line from the respective point on the c.g. envelope shown in figure 3-14, and place a point at the intersection of the two lines. If the point is within the diagonal lines, the loading arrangement meets all balance requirements.

The following is an actual weight and balance computation using the graphs in figure 3-13 and 3-14. For this example, assume that the aircraft has an empty weight of 1,386.0 pounds and a moment of 52,772.0 pound-inches. The index

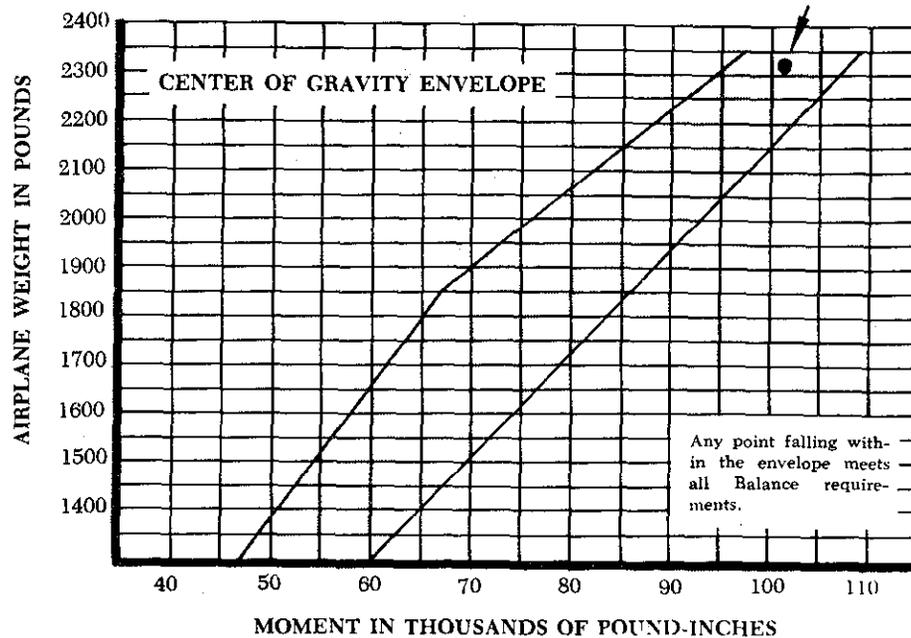


FIGURE 3-14. Center of gravity envelope.

number for the empty weight of the aircraft is developed by dividing the empty-weight moment by 1,000. This gives an index number of 52.8 for the airplane's empty-weight moment. Load the aircraft to determine whether the c.g. will fall within the diagonal lines of figure 3-14. Arrange item weights and index numbers in an orderly form to facilitate adding.

Item	Weight (lbs.)	Moment (thousands of lb.-in.)
Acft. EW	1,386.0	52.8
Oil	19.0	- 0.4
Pilot & copilot	340.0	12.2
Rear passengers (two)	340.0	24.1
Baggage	20.0	1.9
Fuel	245.0	11.8
Total	2,350.0	102.4

The total airplane weight in pounds is 2,350.0, and the moment is 102.4. Locate this point (2,350 @ 102.4) on the c.g. envelope illustrated in figure 3-14. Since the point falls within the diagonal lines, the loading arrangement meets all weight-and-balance requirements.

ELECTRONIC WEIGHING EQUIPMENT

Electronic weighing equipment greatly simplified the mechanics of weighing large, heavy aircraft. Figure 3-15 shows one type of electronic scales. The complete weighing kit is contained in a portable carrier. Included in the kit are a steel tape, plumb bobs, spirit level, straightedge, hydrometer (for determining the fuel specific gravity) and the load cells. The load cells are actually strain gages that reflect the load imposed upon them by the aircraft in terms of voltage change. This change is indicated on a scale that is calibrated to read in pounds.

One load cell is placed between the jack-pad and the jack at each weighing point. Each load cell must be balanced or "zeroed" before applying any load to the cell. After completing the weighing operation, remove all load from the cells and check to see if the cell reading is still zero. Any deviation from zero is referred to as the "zero scale shift" and constitutes the tare when using electronic weighing scales. The direction of shift is the factor that determines whether the tare is added to or subtracted from the scale reading. Always follow the instructions of the manufacture whose scales you are using.

HELICOPTER WEIGHT AND BALANCE

The weight and balance principles and procedures that have been described apply generally to

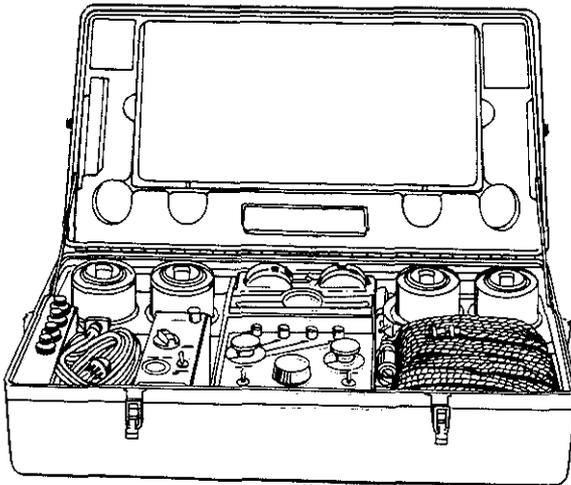


FIGURE 3-15. Aircraft electronic weighing kit.

helicopters. Each model helicopter is certificated for a specific maximum gross weight. However, it cannot be operated at this maximum weight under all conditions. Combinations of high altitude, high temperature, and high humidity determine the density altitude at a particular location. This, in turn, critically affects the hovering, takeoff, climb, autorotation, and landing performance of a helicopter. A heavily loaded helicopter has less ability to withstand shocks and additional loads caused by turbulent air. The heavier the load, the less the margin of safety for the supporting structures, such as the main rotor, fuselage, landing gear, etc.

Most helicopters have a much more restricted c.g. range than do airplanes. In some cases this range is less than 3 inches. The exact location and

length of the c.g. range is specified for each helicopter and usually extends a short distance fore and aft of the main rotor mast or the centroid of a dual rotor system. Ideally, the helicopter should have such perfect balance that the fuselage remains horizontal while in a hover, and the only cyclic adjustment required should be that made necessary by the wind. The fuselage acts as a pendulum suspended from the rotor. Any change in the center of gravity changes the angle at which it hangs from this point of support. More recently designed helicopters have loading compartments and fuel tanks located at or near the balance point. If the helicopter is not loaded properly and the c.g. is not very near the balance point, the fuselage does not hang horizontally in a hover. If the c.g. is too far aft, the nose tilts up, and excessive forward cyclic control is required to maintain a stationary hover. Conversely, if the c.g. is too far forward, the nose tilts down and excessive aft cyclic control is required. In extreme out-of-balance conditions, full fore or aft cyclic control may be insufficient to maintain control. Similar lateral balance problems may be encountered if external loads are carried.

Upon delivery by the manufacturer, the empty weight, empty weight c.g., and the useful load are noted on the weight and balance data sheet in the helicopter flight manual. If, after delivery, additional fixed equipment is added or removed, or if a major repair or alteration is made, which may affect the empty weight, empty weight c.g., or useful load, the weight and balance data must be revised. All weight and balance changes should be entered in the appropriate aircraft record.